Chapter 03
Lecture Outline*

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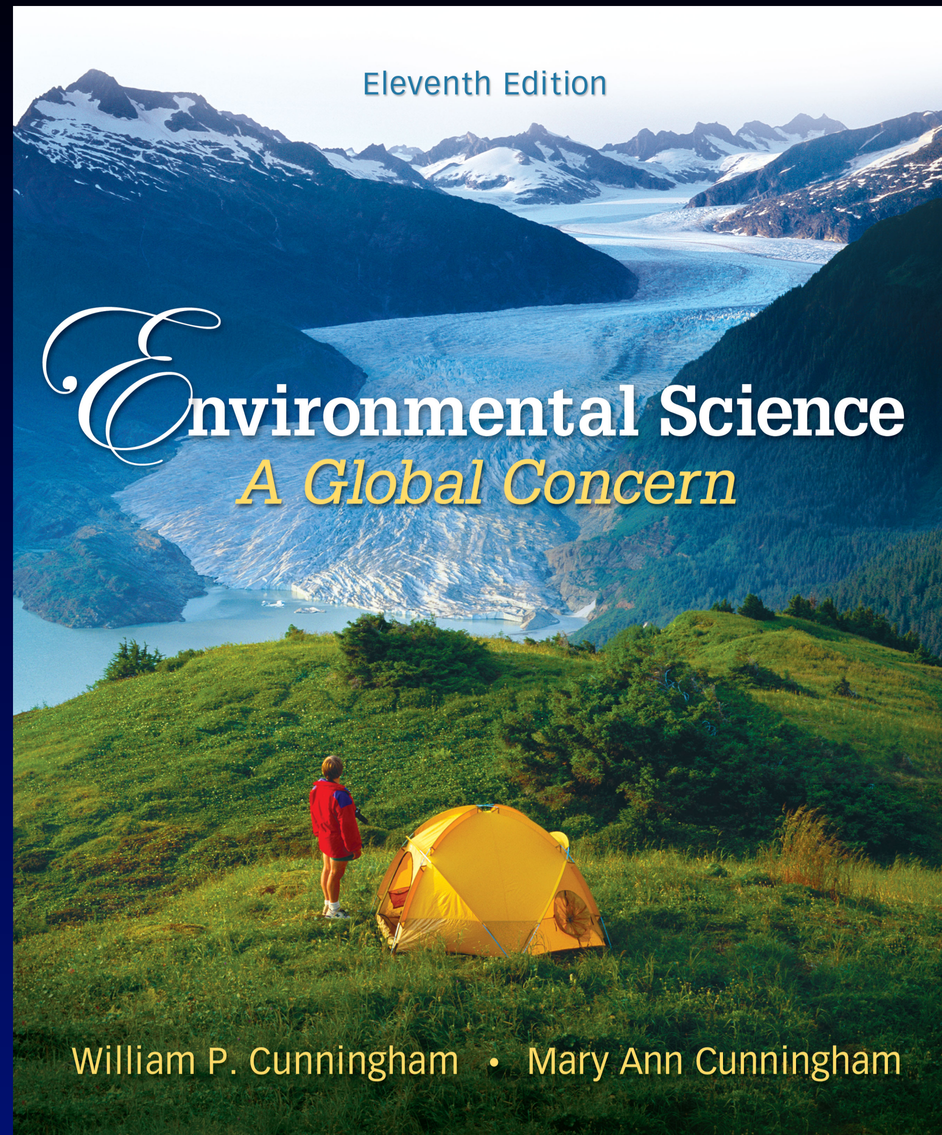

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Matter, Energy, and Life

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Outline

- Elements of Life
- Organic Compounds and Cells
- Energy
  - Laws of Thermodynamics
  - Photosynthesis/Respiration
- Ecosystems
  - Food Chains
  - Ecological Pyramids
  - Material Cycles

Introduction

- Ecology is the scientific study of the relationship between organisms and their environment.

- At the core of the study of ecology is a question about how matter and energy are exchanged between organisms and their surroundings. This chapter looks at matter and energy.

Elements of Life

- Matter - everything that has mass and takes up space
  - Solid - Liquid - Gas = 3 states of matter
- Matter is neither created nor destroyed but rather re-cycled over and over. The atoms in your body may have been in a dinosaur.
- The idea that matter cannot be destroyed but is simply transformed from one form to another is termed conservation of matter.

Elements

- Matter consists of elements.

- Elements - substances that cannot be broken down into simpler forms by ordinary chemical reactions
  - 118 elements, but just four (oxygen, carbon, hydrogen and nitrogen) make up 96% of the mass of living organisms.

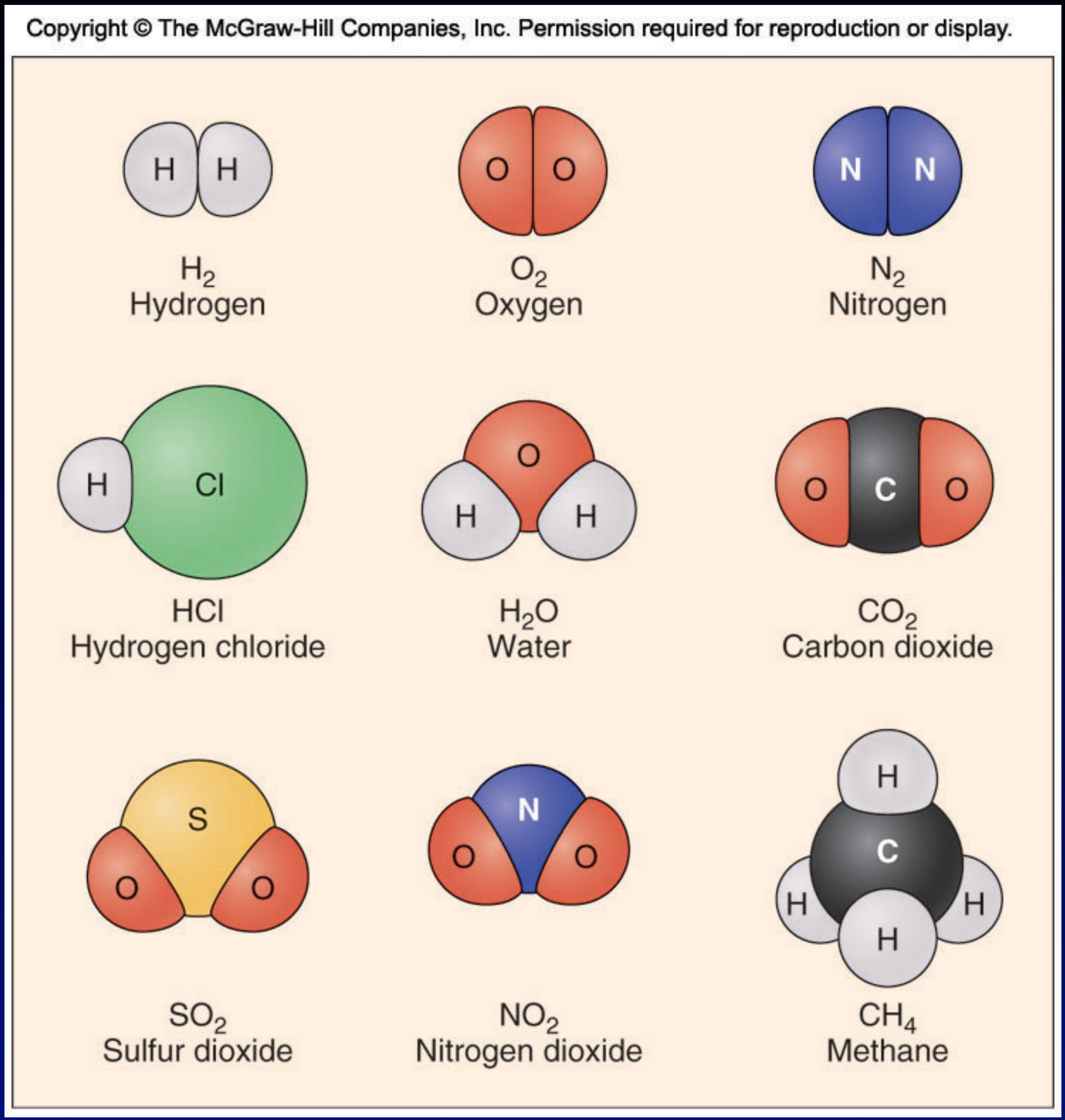
Elements of Life

- All elements are composed of atoms.
- Atoms - smallest particles exhibiting characteristics of the element
- Atoms are composed of:
  - Protons (+) - Neutrons - Electrons (-)
  - Protons and neutrons are in the nucleus; electrons orbit.
  - Atomic Number: Number of protons
  - Isotope - forms of an element differing in atomic mass due to the fact that the isotopes have different numbers of neutrons

Chemical Bonds

- Compound - substance composed of different kinds of atoms
  - Molecule: two or more atoms joined together
  - Chemical Bond - forces (chemical energy) holding atoms together in molecules
    - Ionic - Atoms with opposite charges (ions) form a bond e.g. Na+ and Cl^- .
    - Covalent - atoms share electrons (but not always equally). For example, in water the oxygen attracts the electrons more strongly than the hydrogens do, so the hydrogens have a slight positive charge and the oxygen a slight negative charge.

Common Molecules



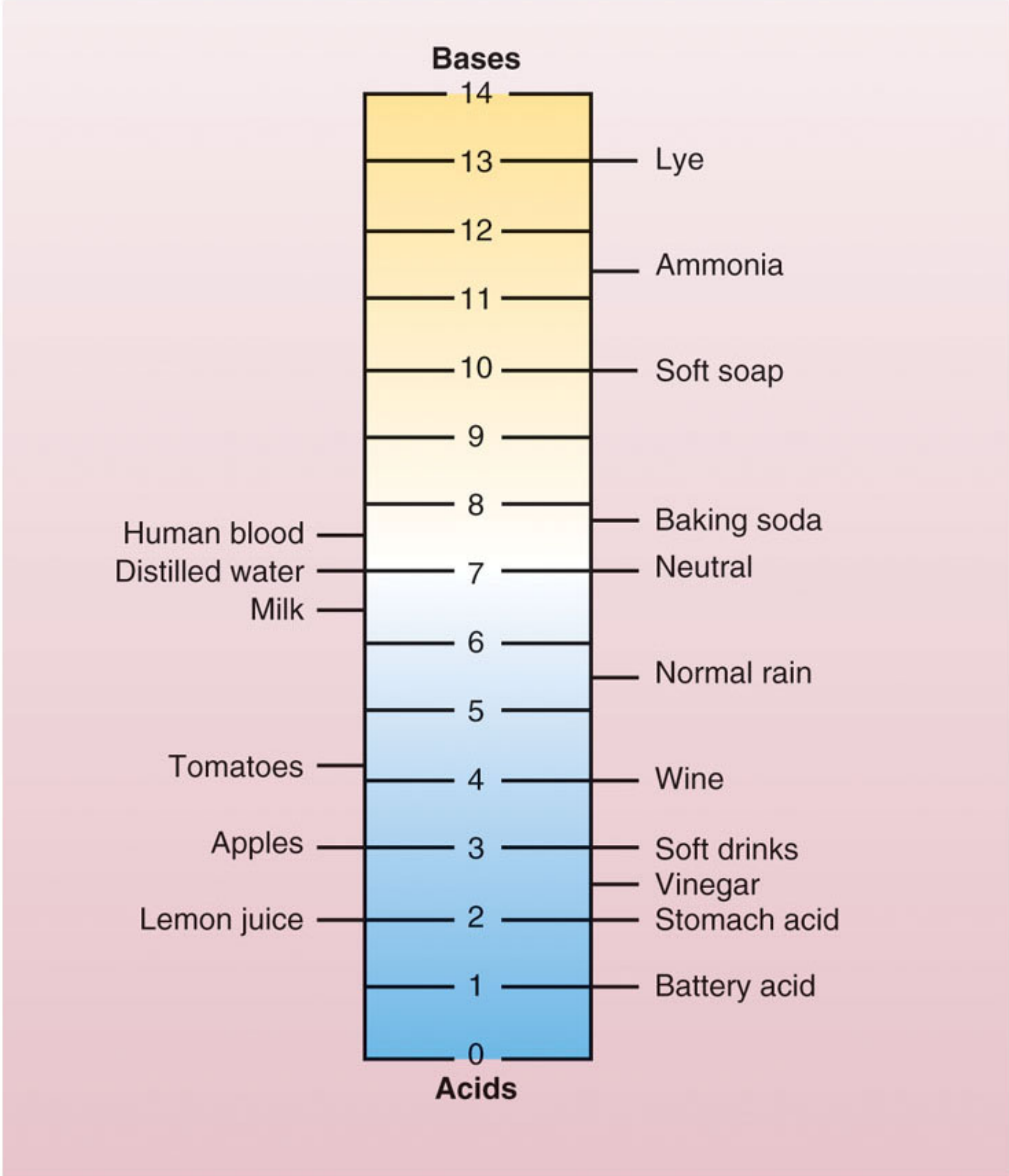
Oxidation and Reduction

- When an atom gives up one or more electrons, it is oxidized.
- When an atom gains electrons, it is reduced.
- Oxidation and reduction are an important part of how organisms gain energy from food.
- Forming bonds uses energy; breaking bonds releases energy.
- Activation energy is often needed to begin a reaction (e.g. match needed to start a fire).

Ions, Acids, and Bases

- Ions - atoms that contain more or fewer electrons than protons and therefore have a positive or negative charge
  - Anions have a negative charge.
  - Cations have a positive charge.
- Acids - substances that release hydrogen ions in water
- Bases - substances that readily bond with hydrogen ions
  - pH scale: logarithmic; each step is 10X
  - 0 to 7 is acidic / 7 is neutral / 8 to 14 is basic

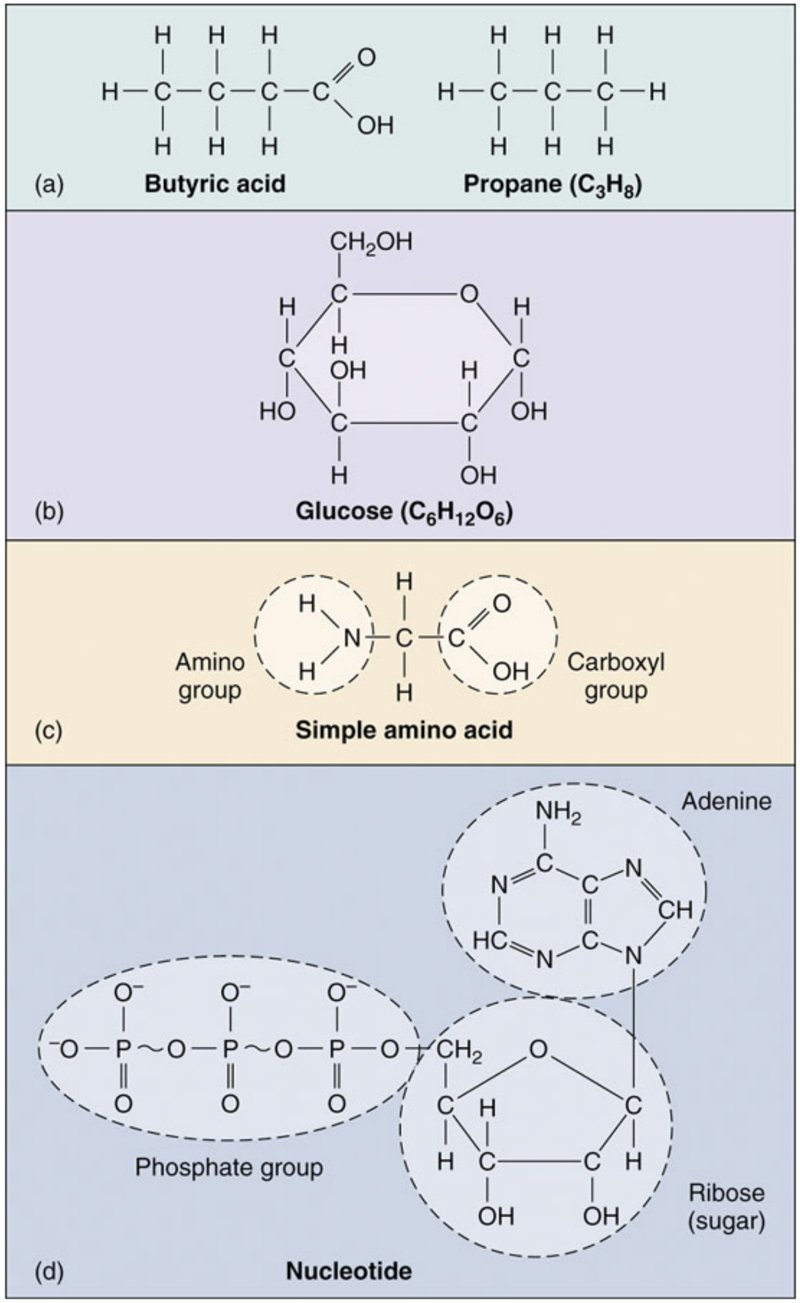
pH Scale


Bases
14
13
Lye
12
Ammonia
11
10
Soft soap
9
8
Human blood
Baking soda
Distilled water
7
Neutral
Milk
6
Normal rain
5
Tomatoes
4
Wine
Apples
3
Soft drinks
Vinegar
Lemon juice
2
Stomach acid
1
Battery acid
0
Acids

Organic Compounds

- Organic Compounds - Material making up biomolecules, which in turn make up living things. All organic compounds contain carbon.

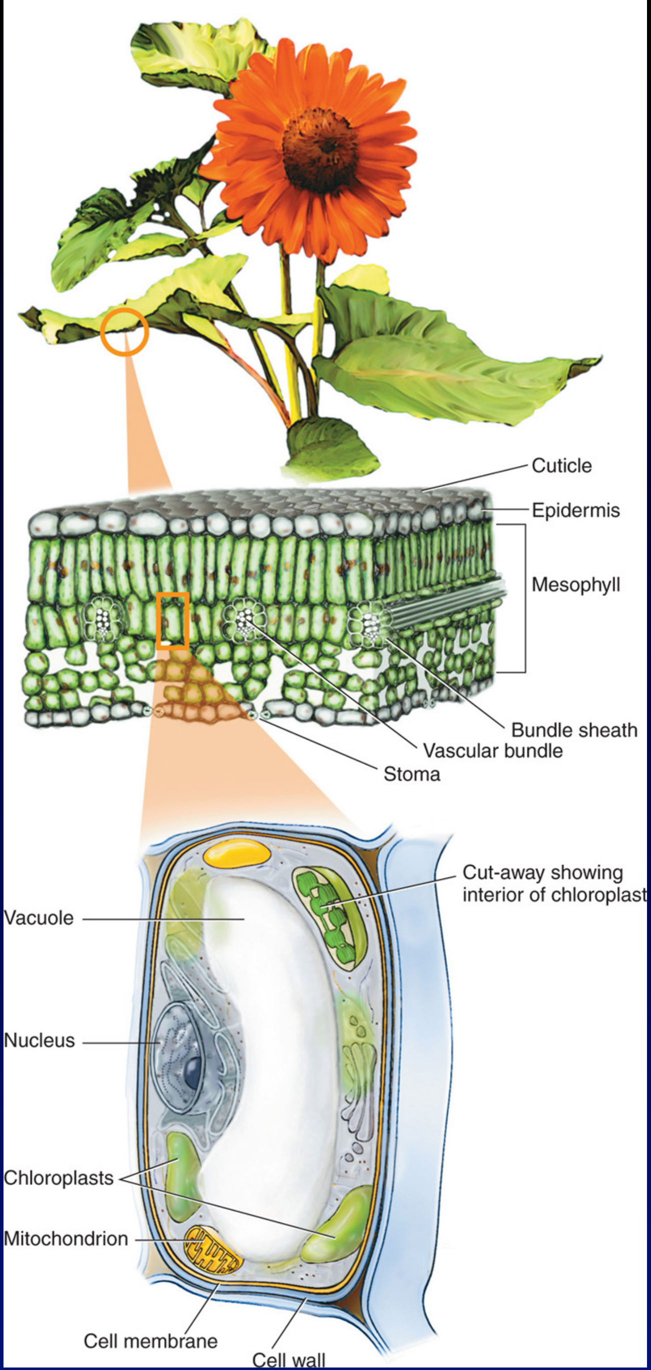
- Four major categories of organic compounds:
  - Lipids
  - Carbohydrates
  - Proteins
  - Nucleic Acids



(a)
Butyric acid
Propane (C_3H_8)
(b)
Glucose ($C_6H_{12}O_6$)
Amino group
Carboxyl group
(c)
Simple amino acid
Adenine
Phosphate group
Ribose (sugar)
(d)
Nucleotide

Cells

- Cells - minute compartments in a living organism which carry out processes of life
  - Surrounded by lipid membrane controlling flow of materials in and out of cell
  - Interior may be sub-divided into organelles and sub-cellular particles.
- Enzymes - Molecular catalysts regulating chemical reactions. Enzymes are usually proteins.
- Metabolism - multitude of enzymatic reactions performed by an organism


Cuticle
Epidermis
Mesophyll
Bundle sheath
Vascular bundle
Stoma
Cut-away showing interior of chloroplast
Vacuole
Nucleus
Chloroplasts
Mitochondrion
Cell membrane
Cell wall

Energy

- Energy - ability to do work
  - Kinetic - energy in moving objects
  - Potential - stored energy
    - Chemical - stored in food or fossil fuels

- Heat - Energy that can be transferred between objects of different temperature. When a substance absorbs heat, the motion of its molecules increases and it may change state (e.g. a liquid may become a gas). Evaporation and condensation help distribute heat around the globe.

Thermodynamics

- Energy must be supplied (from the sun) to keep biological processes running, because as it flows through the various biological processes, it becomes dissipated.

- First Law of Thermodynamics - Energy is neither created nor destroyed.

- Second Law of Thermodynamics - With each successive energy transfer, less energy is available to perform work.
  - Entropy (disorder) increases.

Energy for Life

- Ultimately, most organisms depend on the sun for the energy needed to carry out life processes.
- A few very ancient organisms called archaea are able to get their energy from inorganic compounds that bubble up from vents in the sea floor or from hot springs. These organisms represent one-third of all the biomass on the planet. The methane generated by these undersea communities could be a source of natural gas for us.

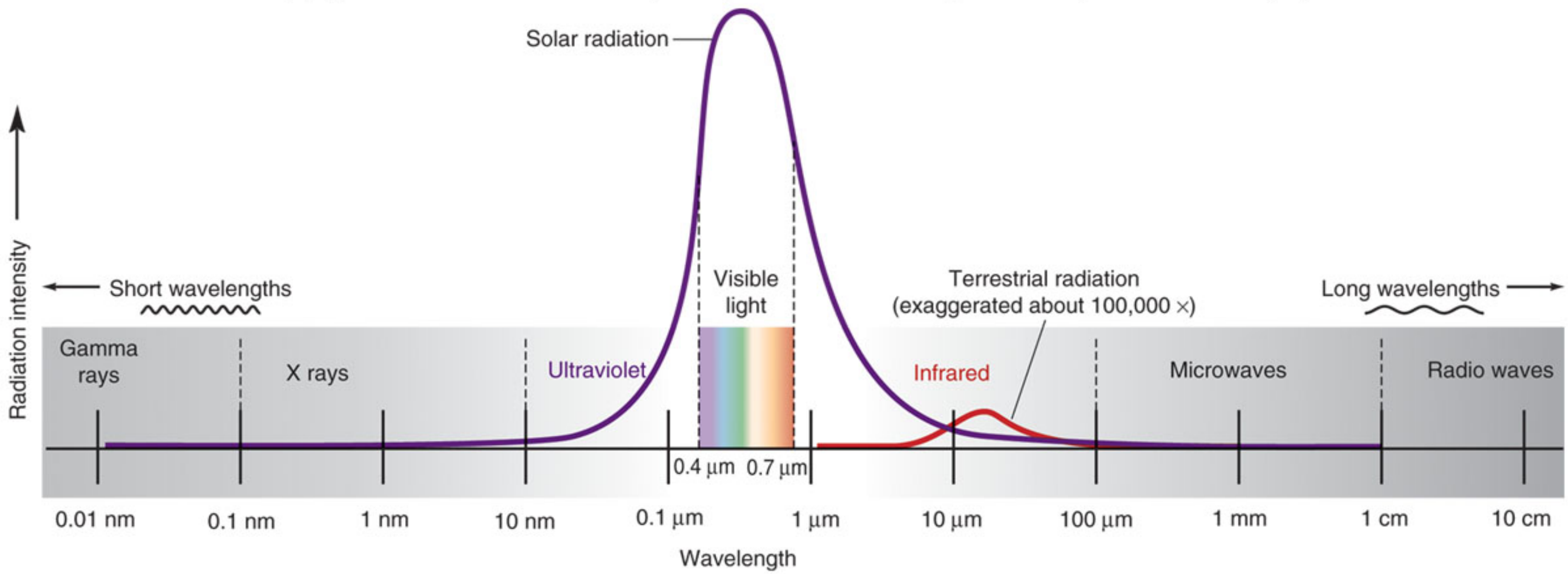
Energy from the Sun

- Solar energy is essential for (2) reasons:
  - ❖ Warmth - Most organisms can exist only in a relatively narrow temperature range.
  - ❖ Photosynthesis in plants
    - Radiant energy is transformed into useful, high-quality chemical energy in the bonds of organic molecules. All life on Earth depends on photosynthesis.

Energy For Life

- Of all solar radiation reaching the earth's surface, about 10% is ultraviolet, 45% is visible, and 45% is infrared.
  - Most of energy is absorbed by land or water, or reflected back into space.
    - Only about 1-2% of the sunlight falling on plants is captured for photosynthesis.

Electromagnetic Spectrum

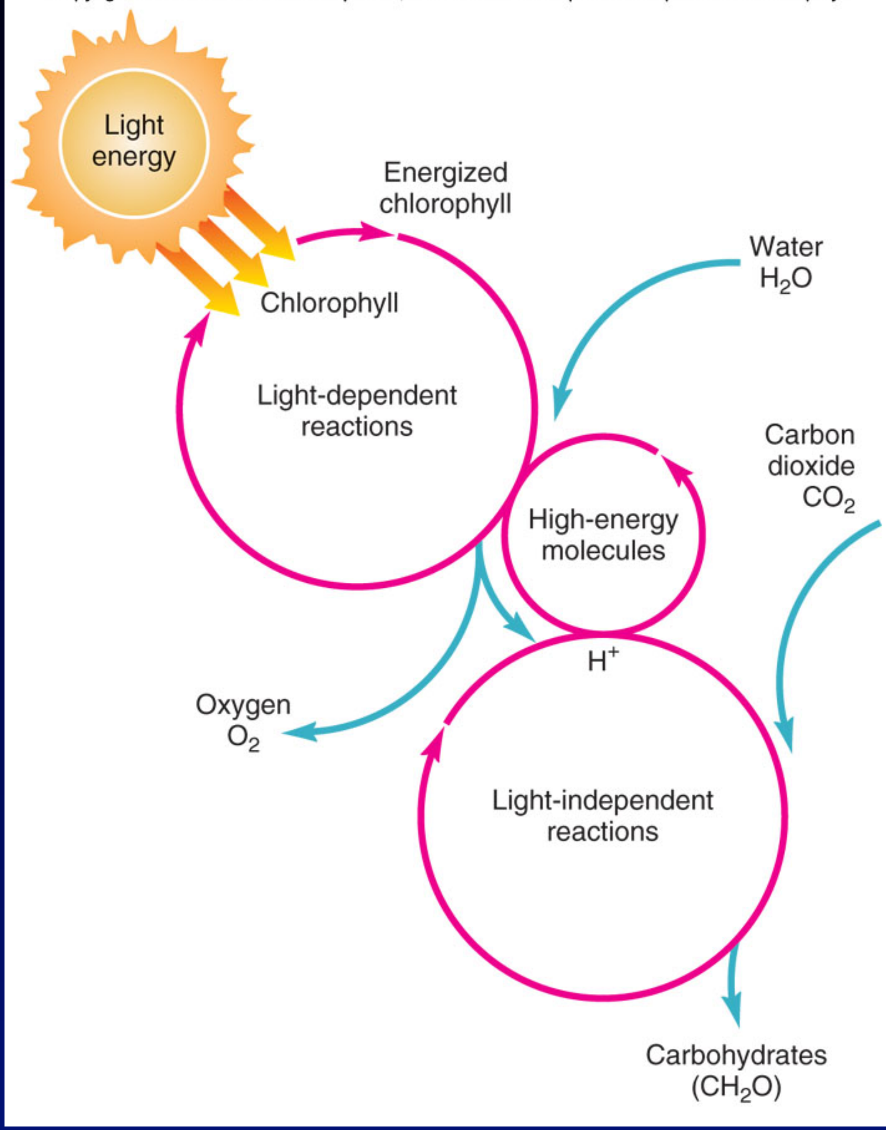


Photosynthesis

- Occurs in organelles called chloroplasts within plant cells
- $6H_20 + 6CO_2$ + solar energy = $C_6H_{12}O_6 + 6O_2$

- Water and carbon dioxide in the presence of sunlight and chlorophyll (the green pigment in chloroplasts) yield glucose (sugar) and oxygen.
- Glucose serves as primary fuel for all metabolic processes. Energy in its chemical bonds can be used to make other molecules such as proteins or it can drive movement, transport, etc.

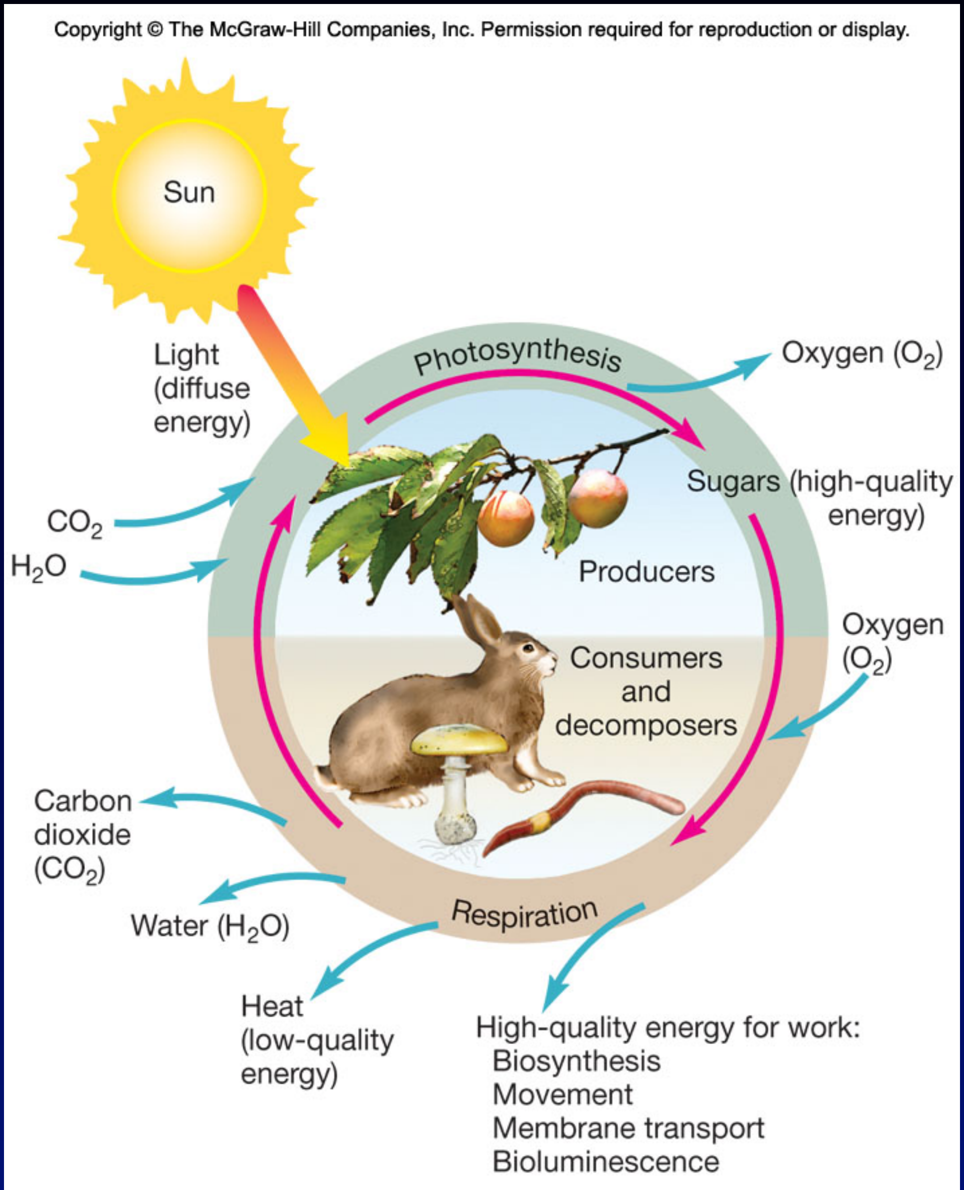
Photosynthesis



Cellular Respiration

- Photosynthesis captures energy, while cellular respiration releases energy.
  - Cellular respiration splits carbon and hydrogen atoms from sugar and recombines them with oxygen to re-create carbon dioxide and water (opposite of photosynthesis).
  - This is how animals get all their energy. The reason that you need to breathe is to supply this pathway with oxygen.
  - $C_6H_{12}O_6 + 6O_2 = 6H_2O + 6CO_2$ + energy

Energy Exchange in Ecosystems



From Species to Ecosystems

- Species - all organisms of the same kind that are genetically similar enough to breed in nature and produce live, fertile offspring
- Population - all members of a species living in a given area at the same time
- Biological Community - all of the populations of organisms living and interacting in a particular area

From Species to Ecosystems

- Ecosystem - biological community and its physical environment
  - The physical environment includes non-living factors such as climate, water, minerals, etc.
  - It is difficult to define the boundaries of an ecosystem. Most ecosystems are open in that they exchange materials and organisms with other ecosystems.

Food Chains and Food Webs

- Photosynthesis is at the base of all ecosystems so photosynthesizers (usually plants) are called the producers.

- Productivity - the amount of biomass produced in a given area in a given period of time. Photosynthesis is called primary productivity because it is basic to all other growth in an ecosystem.

- Secondary productivity - manufacture of biomass by organisms that eat plants

Food Chains and Food Webs

Food Chain - linked feeding series

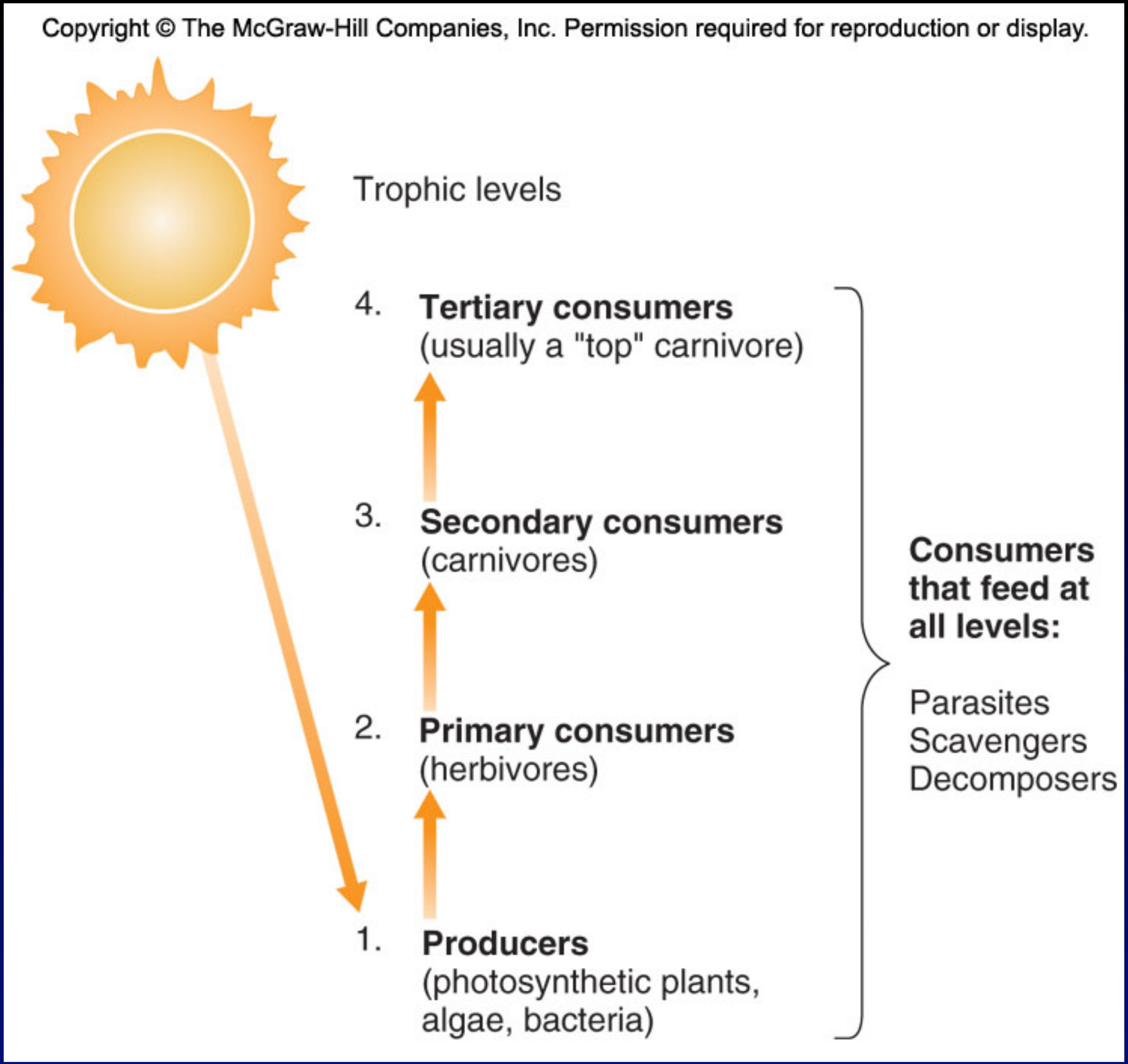
Food Web - Most consumers have multiple food sources.

Trophic level - An organism's feeding status in a food web. Plants are at the producer level while animals are consumers. Animals that eat plants are primary consumers while animals that eat other animals are secondary and tertiary consumers. (Some animals, called omnivores, eat both plants and animals.) Finally, there are organisms that recycle dead bodies and remove waste.

Trophic Levels

- Organisms can also be identified by the type of food they consume:

❖ Herbivores	(Plants)	{Deer}
❖ Carnivores	(Meat)	{Wolves}
❖ Omnivores	(Plants/Meat)	{Bears}
❖ Scavengers	(Carcasses)	{Crows}
❖ Detritivores	(Debris)	{Ants}
❖ Decomposers	(All)	{Bacteria}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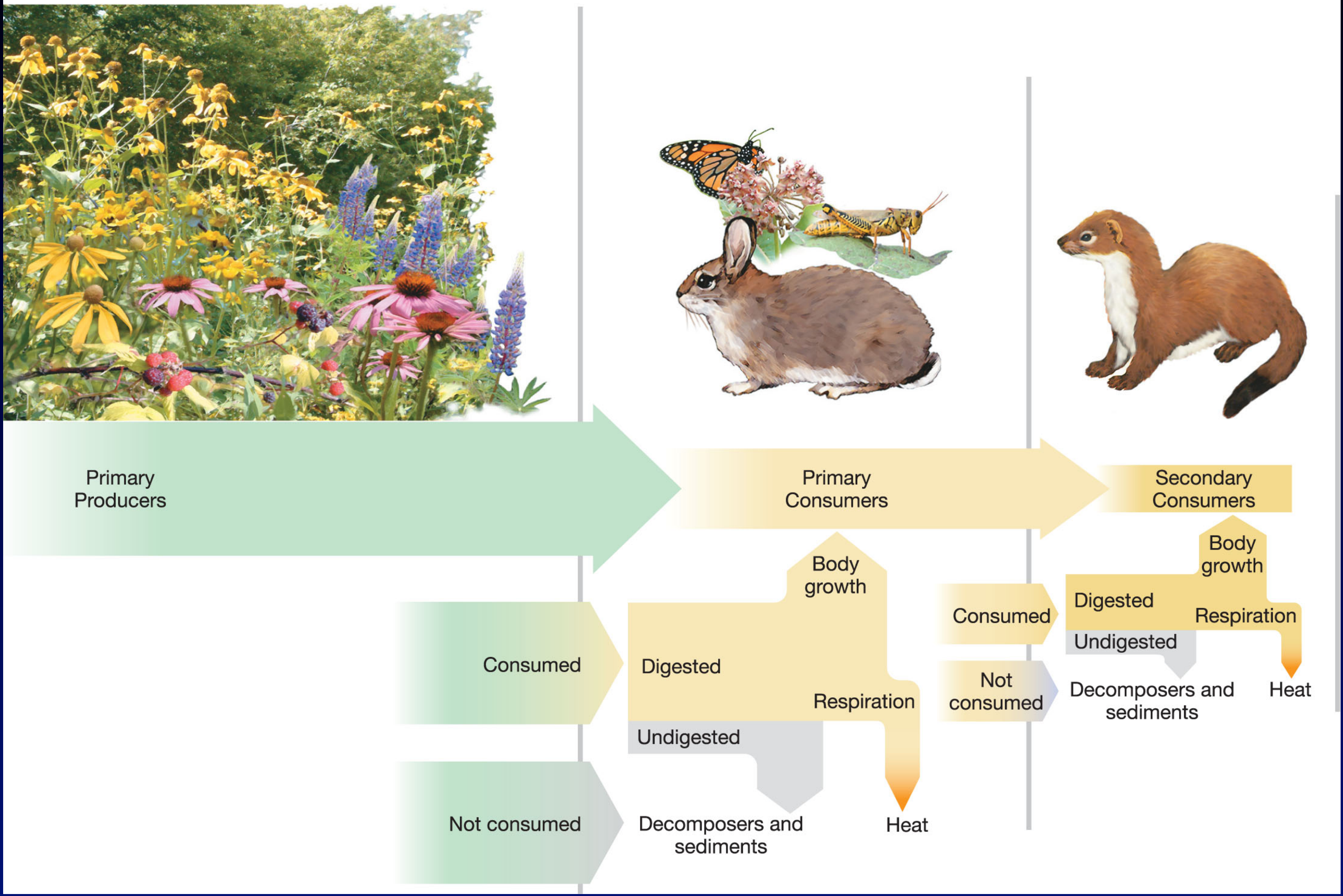
Trophic levels
4. Tertiary consumers
(usually a "top" carnivore)
3. Secondary consumers
(carnivores)
2. Primary consumers
(herbivores)
1. Producers
(photosynthetic plants, algae, bacteria)
Consumers that feed at all levels:
Parasites
Scavengers
Decomposers

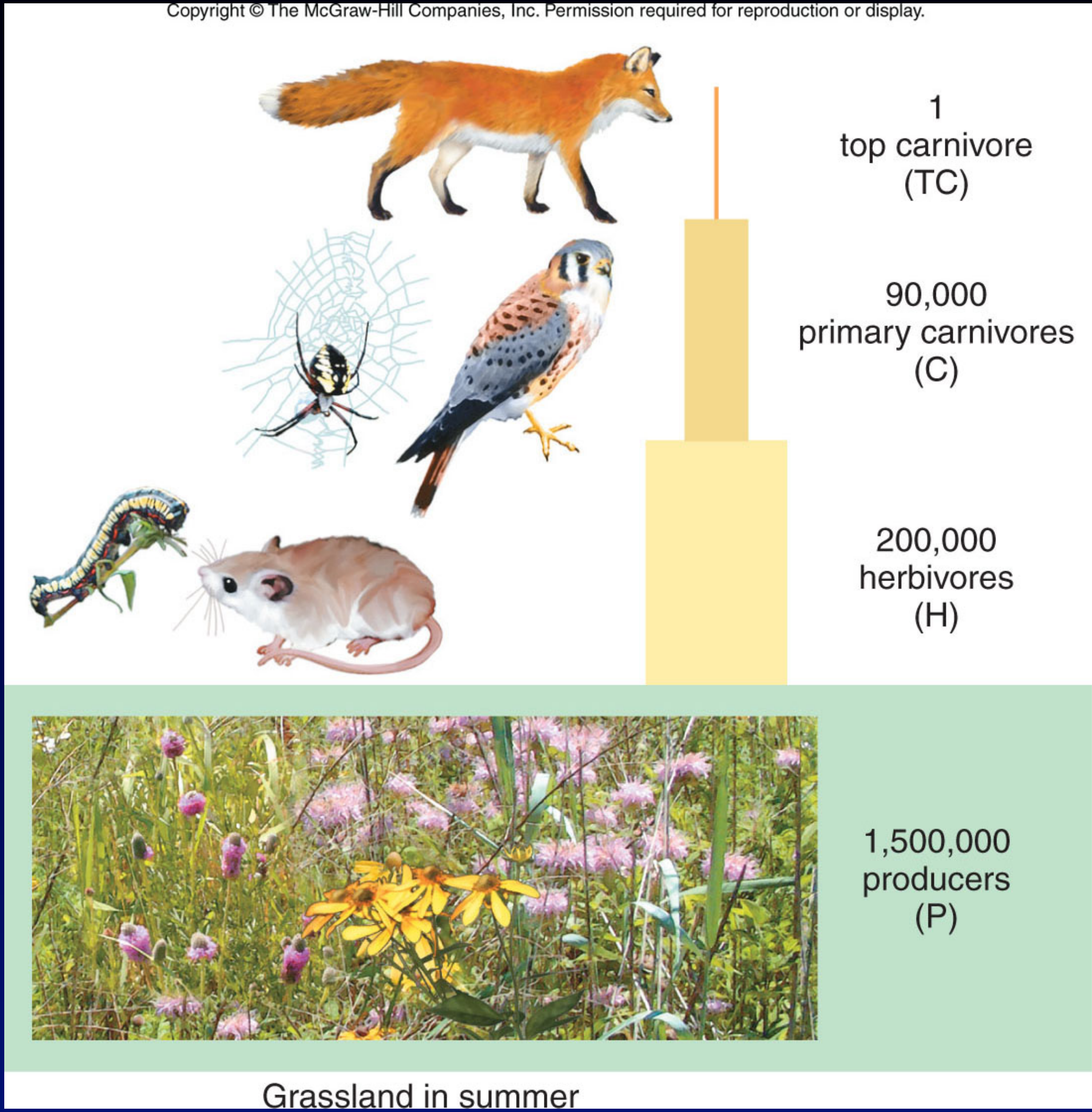
Ecological Pyramids

- If the organisms at various trophic levels are arranged diagrammatically, they form a pyramid with many more producers than consumers.
- Due to the Second Law of Thermodynamics, energy is lost at each level of the pyramid.
  - Energy is lost as heat in metabolic processes.
  - Predator efficiency < 100%
  - 10% Rule (Energy / Biomass)
    - 100 kg clover
      - 10 kg rabbit
        - 1 kg fox

Biomass Pyramid



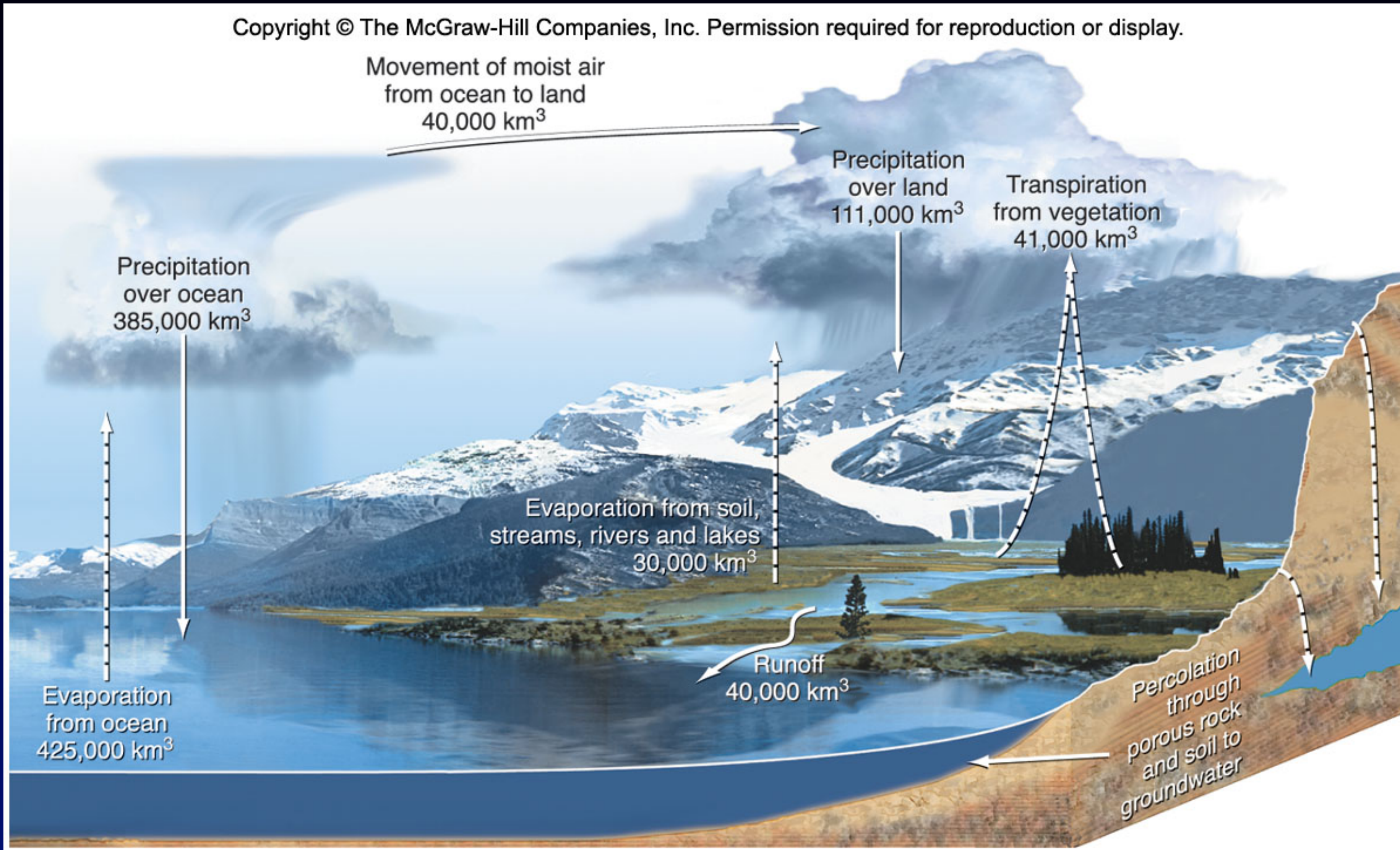
Energy Pyramid



Material Cycles

- Hydrologic Cycle - path of water through the environment
  - Solar energy continually evaporates water stored in the oceans and land, and distributes water vapor around the globe.
    - Condenses over land surfaces, supporting all terrestrial systems
      - Responsible for cellular metabolism, nutrient flow in ecosystems, and global distribution of heat and energy

Hydrologic Cycle



Carbon Cycle

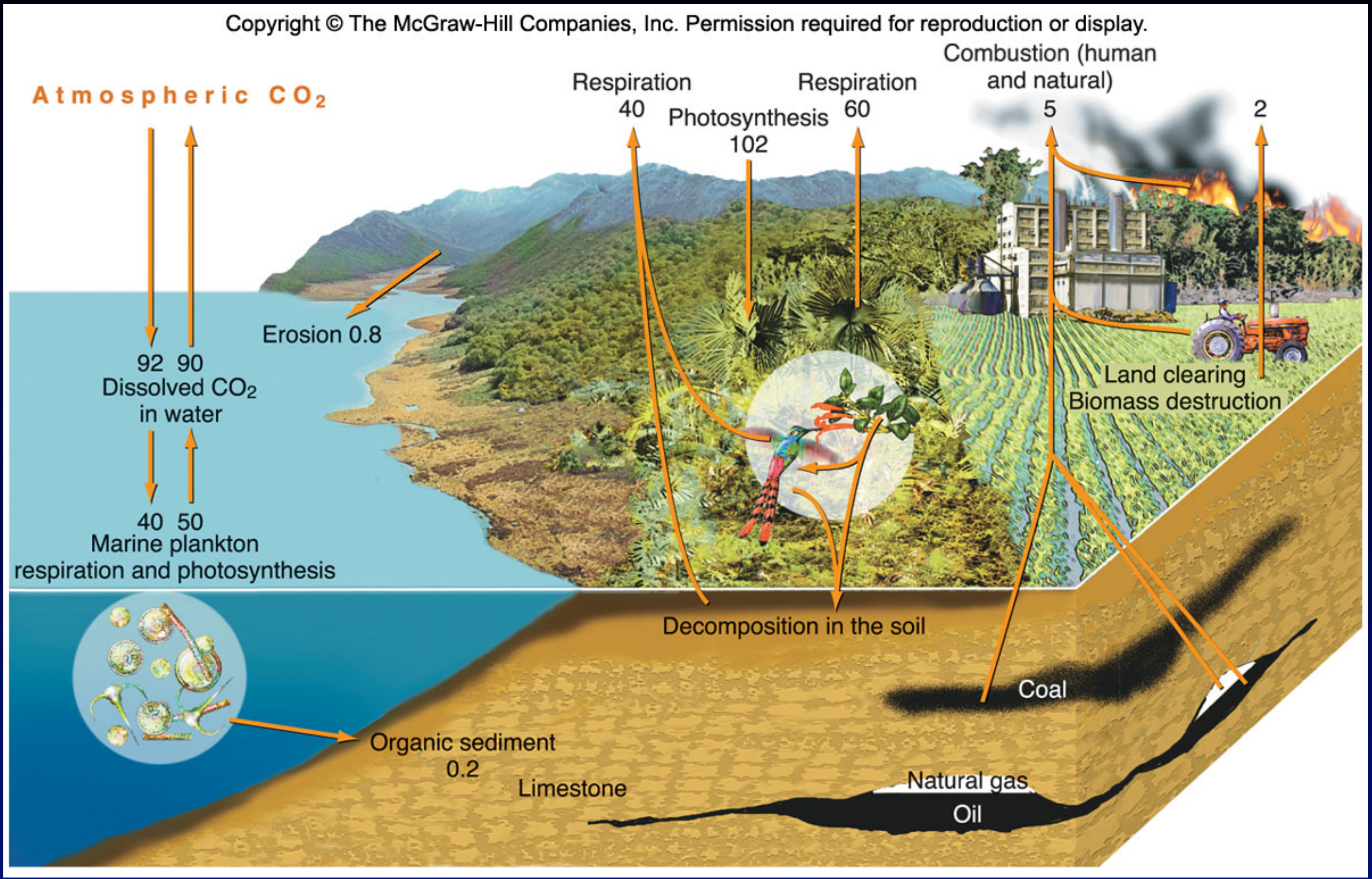
- Begins with intake of CO_2 during photosynthesis. Carbon atoms are incorporated into sugar which is eventually released by cellular respiration either in the plant or in organisms that consumed it.

- Sometimes the carbon is not recycled for a long time. Coal and oil are the remains of organisms that lived millions of years ago. The carbon in these is released when we burn them. Some carbon is also locked in calcium carbonate (shells, limestone).

Carbon Cycle

- The parts of the cycle that remove carbon dioxide from the atmosphere (vegetation) are called carbon sinks.
- The parts of the cycle that release carbon dioxide are called carbon sources.
- Burning of fuels generates huge quantities of carbon dioxide that cannot be taken up fast enough by the carbon sinks. This excess carbon dioxide contributes to global warming.

Carbon Cycle



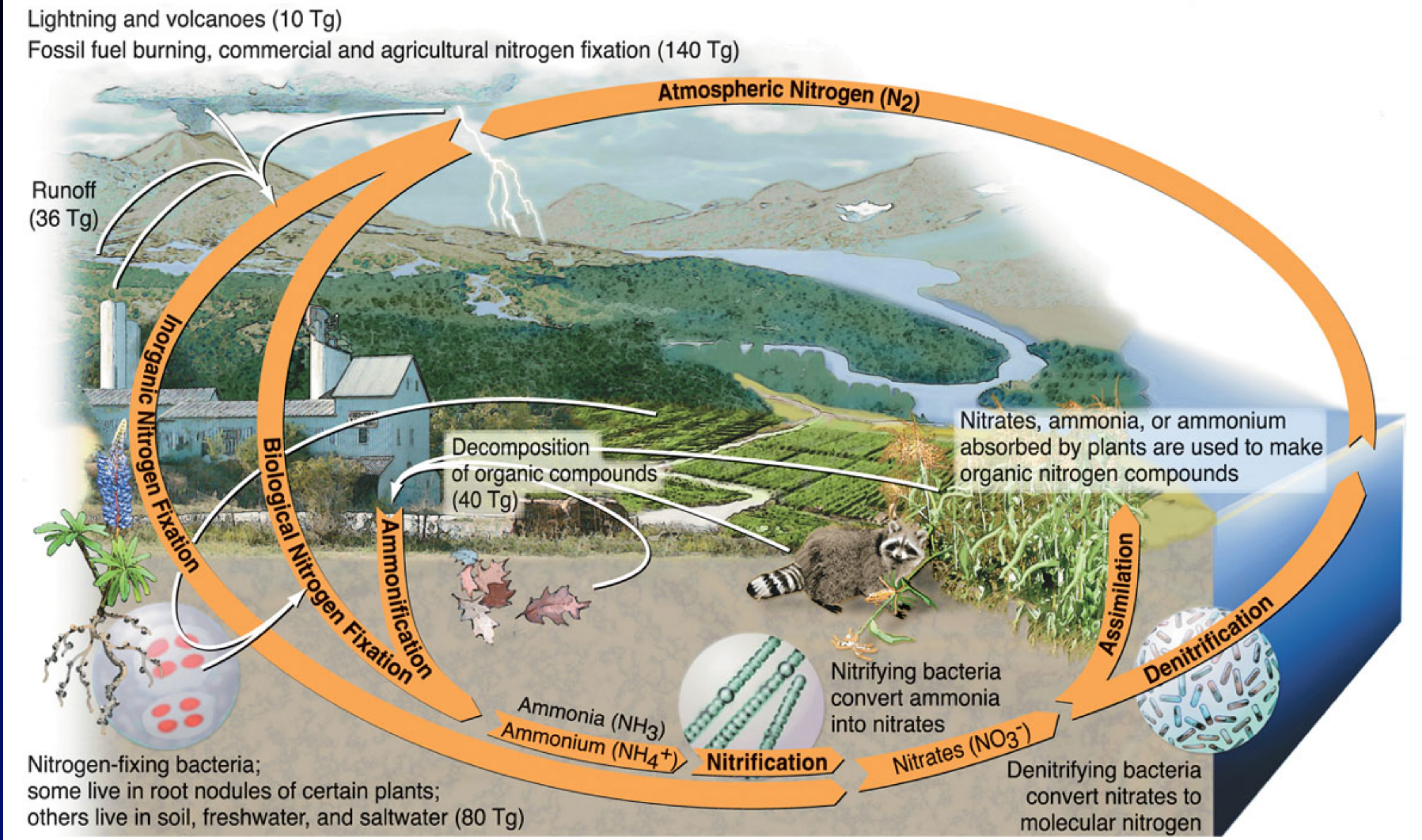
Nitrogen Cycle

- Nitrogen is needed to make proteins and nucleic acids such as DNA (Chap. 2).
- Plants take up inorganic nitrogen from the environment and build protein molecules which are later eaten by consumers.
  - ❖ Nitrogen-fixing bacteria change nitrogen to a more useful form by combining it with hydrogen to make ammonia. Other bacteria convert ammonia to nitrites and nitrates, which can be taken up by plants to make proteins.
    - Members of the bean family (legumes) have nitrogen-fixing bacteria living in their root tissue.

Nitrogen Cycle

- Nitrogen re-enters the environment:
  - Death of organisms
  - Excrement and urinary wastes
- Nitrogen re-enters atmosphere when denitrifying bacteria break down nitrates into N_2 and nitrous oxide (N_2O) gases.
  - Humans have profoundly altered the nitrogen cycle via use of synthetic fertilizers, nitrogen-fixing crops, and fossil fuels.

Nitrogen Cycle



Nitrogen nodules on bean plant

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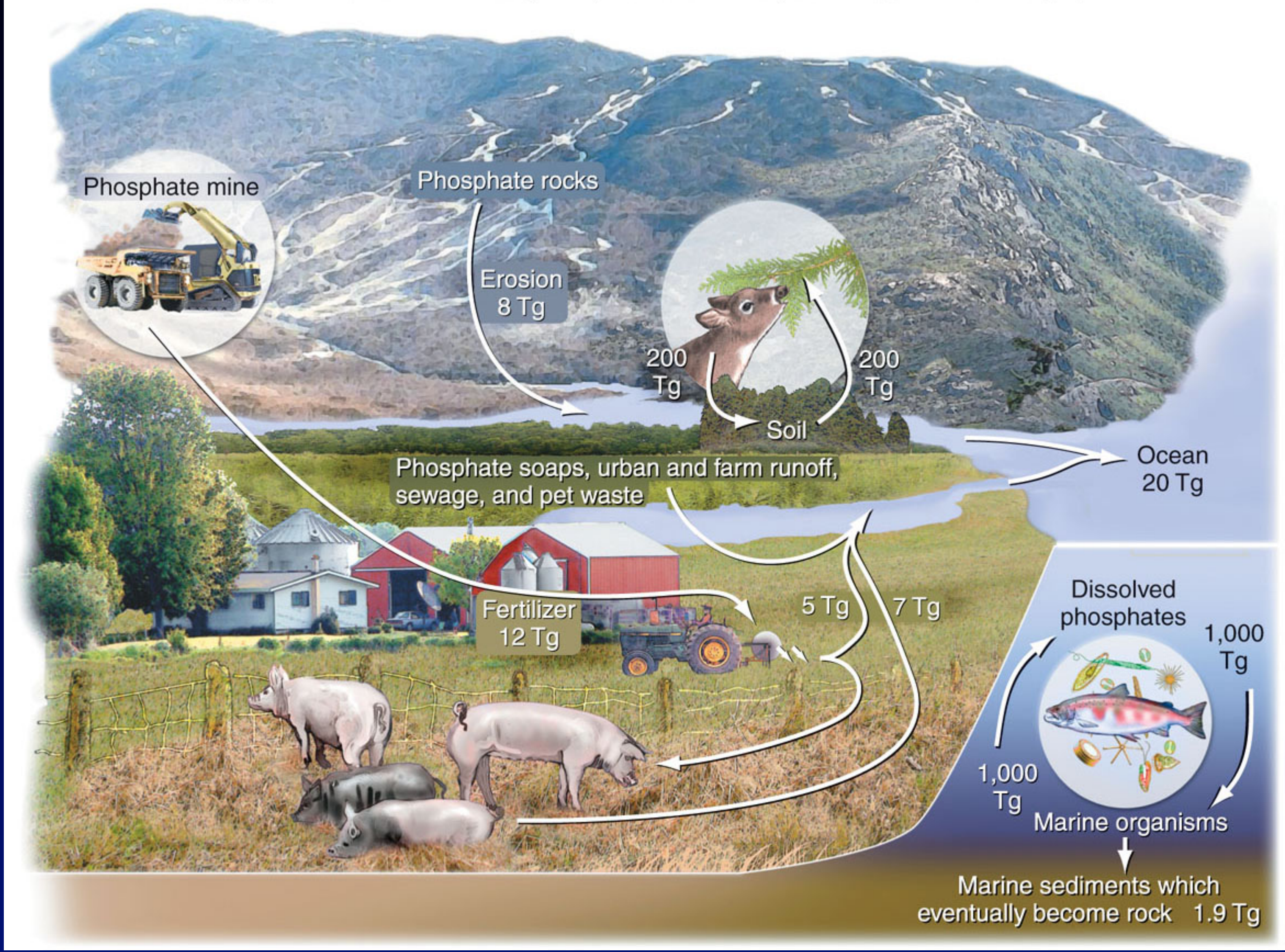
Phosphorous Cycle

- Phosphorous is needed to make DNA, ATP (the energy currency of the cell) and other important biomolecules (Chap. 2).
- Phosphorous compounds are leached from rocks and minerals and usually transported in aqueous form.
  - Taken in and incorporated by producers
    - Passed on to consumers
      - Returned to environment by decomposition
- Cycle takes a long time as deep ocean sediments are significant sinks

Phosphorus Cycle



Sulfur Cycle

- Most sulfur is tied up in underground rocks and minerals. Inorganic sulfur is released into air by weathering and volcanic eruptions.
  - ❖ Cycle is complicated by large number of oxidation states the element can assume.
  - ❖ Human activities release large amounts of sulfur, primarily by burning fossil fuels.
    - Important determinant in rainfall acidity

Sulfur Cycle